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Decision Analysis Consulting Projects

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13. ABSTRACT *(Maximum 200 words)*

This report discusses a decision analysis course taught the fall semester of 1994 at the United States Air Force Academy. Students assisted five companies in the Colorado Springs business community make multi-million dollar, strategic decisions. The consultation-based format of this course provided an excellent opportunity for the students to solve real-world problems in a team-oriented manner. The students learned that such problems are not standard textbook problems. There are no answers in the back of the book. Rather, they learned that real-world problems require modeling assumptions, clear communication, and the ability to get along with others. Both the students and the companies benefited from this course. The companies received insight to one decision, while the students participated in an unique learning experience.

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1. INTRODUCTION

The purpose of this report is to describe "Principles and Practice of Decision Analysis," an Operations Research course taught at the United States Air Force Academy in the fall semester of 1994. The goal of this course was to assist a decision maker (client) in formulating their decision problem. This required the students to work as part of a consulting team, interact with their client, and present their findings. An integral part of this report is a discussion of the student consulting projects.

When teaching this course, there is always one major concern: Can undergraduate students (i.e., Air Force Academy cadets), with many time-consuming activities and minimal "business-sense," gain enough expertise in a single semester to successfully consult with a client? The answer, thus far, has been a resounding yes.

Students gained a full appreciation and understanding of decision analysis by applying it to a "real" decision problem. It was an opportunity for the students to use their knowledge from the class and experience the satisfaction of helping a client. Each client plans to act on the recommendations of their student consulting team. In summary, "Principles and Practice of Decision Analysis" provided an excellent opportunity for the students to solve real-world problems with a team-oriented approach.

The remainder of this chapter describes the content of this course and characteristics of students that took this course.

1.1. Course Content

This course provided students the opportunity to assist "real" decision makers, within the Colorado Springs business community, make multi-million dollar, strategic decisions. The consultation-based format of the course required initiative and creativity, the ability to work together in a team, and careful attention to the principles of decision analysis.

The sixteen-week course allowed time to learn the principles of decision analysis first and then practice them in a consulting project. The first eight weeks were devoted to the principles of decision analysis and the last eight weeks to the consulting project. Total in-class contact time was about 30 hours during the first half of the course. Key topics included: influence diagrams, decision trees, decision modeling using DPL (ADA Decision Systems, 1995), financial modeling using spreadsheets, and client interaction skills (including probability encoding). The textbook used for this course was Clemen (1991). In addition, a case study was used to simulate a realistic decision problem -- the students played the role of consultants while the instructor fulfilled the role of the decision maker. During the second half of the course, each student averaged about eight hours a week working on their consulting project.

1.2. Characteristics of Students

There were 28 students (22 seniors and 6 juniors) enrolled in "Principles and Practice of Decision Analysis," majoring in either Operations Research, Math, or Economics. Besides this course, each student had five or six additional academic courses, a professional-military studies course, and one or two physical education courses. Also, each student participated in an intramural sports program twice a week and military training daily. Some students also

participated in intercollegiate sports, while others were involved in the Academy's flying, navigating, or parachuting programs. Thus, a student's time is highly-structured and in short supply. This was a major concern considering the amount of time needed for the consulting projects; however, the students arranged their schedules to spend the necessary time on the projects.

1.3. Coming Attractions

Chapter 2 discusses decision analysis. Chapters 3 through 7 discuss five student consulting projects. Chapter 8 provides concluding remarks.

2. DECISION ANALYSIS

Decision analysis is a learn-by-doing skill with the objective of promoting quality decision making. This is accomplished by "unlocking" the decision maker's mind and capturing what the decision maker knows or doesn't know (information), what the decision maker wants (preferences), and what the decision maker can do (alternatives). Decision analysis mandates clear, focused communication of the decision maker's information, preferences, and alternatives by following a systematic process. This process takes a clearly defined decision; breaks it into small, manageable pieces; and logically aggregates these pieces to produce insight for the decision maker. In summary, decision analysis provides the necessary framework to make quality decisions consistent with what the decision maker knows, wants, and can do.

Each student consulting team applied the decision analysis process to their client's decision problem. The steps of this process are shown in Figure 1.

2.1. Formulation

As shown in Figure 1, the *Formulation* step provides the foundation for the rest of the decision analysis process. Formulation involves clearly identifying the "right" problem, gathering information, defining preferences, and generating alternatives.

Clearly identifying the important factors (information, preferences, and alternatives) that the client brings to a particular decision is vital to the success of any decision analysis effort. Howard (1988) calls this the "clarity test." The clarity test ensures that the consultant and the client have a common understanding of the decision problem.

Influence diagrams (Howard and Matheson, 1981) are tremendously useful tools in formulating the client's decision problem and communicating it throughout the client's organization. Influence diagrams transform the client's opaque decision problem into a transparent one by clearly defining the relevant variables and their interrelationships.

Consider the following influence diagram example (see Figure 2): Suppose a decision maker wants to introduce a new product to the marketplace. In decision analysis, a rounded rectangle represents a value node, a rectangle represents a decision node, and an oval represents a chance node. In this example, the value node represents the decision maker's objective to maximize profit, the decision node is whether to introduce the product or not, and the chance nodes are revenues and costs. Arrows from the decision and chance nodes to the value node mean that they influence profit. Specifically, they describe the interrelationship that *profit = revenues - costs*.

2.2. Modeling

The *Modeling* step is where the consultant constructs a financial model and elicits numerical judgments from the client. The variables and interrelationships represented in the influence diagram are parameters and equations in the financial model. Tradeoffs and assumptions are often necessary to keep this model simple enough to be understandable and solvable, yet robust enough to distinguish among the alternatives.

For each parameter in the financial model (or variable in the influence diagram), the consultant begins by discussing extreme scenarios that may have an affect on the parameter in question. This elicitation procedure counteracts the many biases that are common when eliciting

information from experts (Kahneman, Slovic, and Tversky, 1982). Once these scenarios have been discussed, then the consultant obtains worst-case and best-case values for each parameter. Finally, the consultant obtains a nominal value for each parameter.

After these values have been obtained for each parameter in the financial model, the consultant then determines which of these parameters are sensitive to the client's decision. This analysis often results in a tornado diagram (Clemen, 1991) which depicts the sensitivity of the parameters. The consultant then obtains 10-50-90 values for each sensitive parameter. (10-50-90 values approximate the underlying uncertainty of a sensitive parameter; they represent the 10th, 50th, and 90th percentiles of that parameter.) The non-sensitive parameters are set to their nominal values. This streamlined approach was used in lieu of the probability-encoding process as outlined in Spetzler and Staël von Holstein (1975) and Merkhofer (1987).

2.3. Insight

The goals of the *Insight* step are: 1) evaluate alternatives and recommend a preferred course of action to the client, and 2) conduct what-if analyses to measure the effects of varying model parameters. This step is where the consultant provides insight so that the client can have clarity of action when making their decision.

The next five chapters discuss student consulting projects.

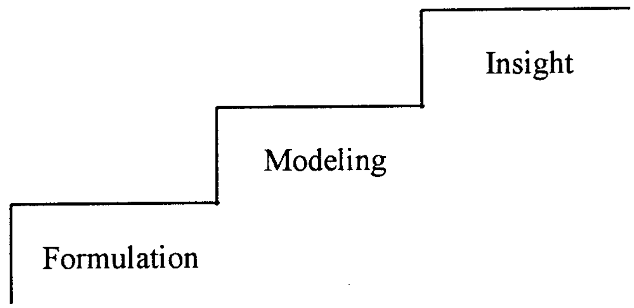

Figure 1. Steps of the Decision Analysis Process

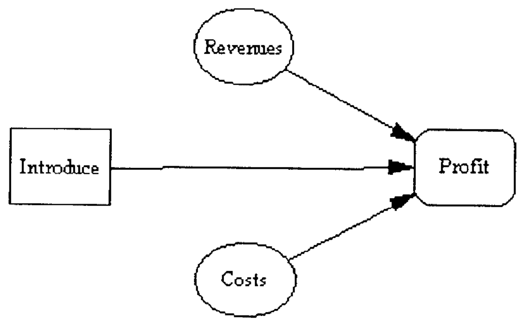

Figure 2. Influence Diagram Example

3. CERAM INCORPORATED

3.1. Introduction to the Problem

Information technology is perhaps one of the fastest growing industries in the world today, and internet services are a very big part of that growth. In response to the increasing demand for internet service providers, a small company based in Colorado Springs, CO, Ceram Incorporated, has developed a hardware kit which they claim simplifies the process of setting up a small regional internet server site. For example, a buyer of this hardware kit would be able to run an internet system at home.

The development of this hardware kit was risky, since it required a significant investment by Ceram. The President/Chief Executive Officer (CEO) of Ceram believed that the current emphasis in the computer world has been on software, not hardware. But market research had shown Ceram that there was definite room for competition in the hardware arena as well. Once Ceram made the decision to develop their hardware kit, they then had to answer the question of how to enter that kit into the marketplace.

To answer this question, Ceram enlisted the aid of a team of United States Air Force Academy cadets to apply decision analysis to their decision problem. Ceram wanted us to analyze the profitability of their three options.

3.2. Options Available to Ceram

The first of these options was basically to franchise Ceram. In other words, Ceram would sell the hardware kit as well as technical support, training, backup systems, etc., to the local

service provider in return for a franchise fee as well as a portion of the revenues from the local server site. This option also required Ceram to be ultimately responsible for the site if something were to go wrong.

The second option for Ceram was to sell the hardware kit only to the local service provider. This option would also include some type of warranty agreement concerning the hardware itself, but would require no other type of support.

The final option Ceram was willing to explore was for Ceram to become the internet server at each local site. This option required Ceram to enter into competition with America OnLine, Prodigy, and other electronic media systems, but on a smaller scale.

3.3. Formulating Ceram's Decision Problem

Again, the decision problem that Ceram faced was to determine which of these options generated the most profit. In formulating Ceram's decision problem, we first had to determine exactly what decisions needed to be made by Ceram in achieving this end. Through consultation with the President/CEO, as well as one of his chief aides, we originally formulated an influence diagram with five decisions (see Figure 3). Further discussion over the course of several meetings eventually led to the conclusion that each of these decisions would be realized when one of the three options was chosen. Figures 3 and 4 show the evolution from the original influence diagram with five decisions to the final influence diagram that only had one decision.

Having simplified Ceram's decision problem to the single decision of which option to pursue, our next step was to determine which variables were relevant to Ceram's decision. Again, over the course of numerous consultations with Ceram, we were able to modify our initial list of

costs and revenues to include only those variables that would affect Ceram's final decision as to which option to consider. From these variables, we developed financial models for each of the three options.

3.4. Financial Modeling of Ceram's Options

Each of these options had slightly different financial models. All obviously required the basic financial equation for profit, i.e., *profit = revenues - costs*, but the actual financial models used in the three options were not the same since different variables were relevant to each option.

In the first option, that of franchising Ceram, the revenues would be earned through a fixed franchising fee, which is incorporated into the price of the hardware kit, as well as a portion of the site revenues. These revenues would be based on the number of subscribers to the local internet site and the revenue per subscriber. The costs associated with this option included the cost of manufacturing the hardware kit, salaries of administrators that would function as technical advisers to the regional sites, and backup inventory cost. Ceram planned to maintain at least ten percent of its total hardware kits produced as backup inventory to fulfill its obligation of maintaining the local server site if something were to happen to the equipment.

In the second option, selling only the hardware kit and the warranty to a local internet service provider, Ceram would earn its revenues from the selling price of the kits. Its costs would be limited to the manufacturing cost of the hardware kits and the costs associated with maintaining a backup inventory.

The final option, running the entire internet operation at the local site itself, was perhaps the most costly. The costs again included the manufacturing costs of the hardware kit and backup

inventory, but it also included the day-to-day costs of running each local server site, as well as administrators to manage those sites. The revenues earned in this option were based on the number of subscribers at each local site and the revenue per subscriber.

3.5. Analysis

Having determined the relevant costs and revenues for each of the three options, the next step was to determine 10-50-90 values of the different variables. Fortunately, Ceram had already completed a great deal of research concerning their proposed expansion into the internet industry. Based on this research, we were able to determine the 10-50-90 values for each variable. Using these values, we determined that the number of hardware kits sold and the selling price of the hardware kits were the most sensitive to Ceram's decision, see Figure 5.

3.6. Recommendations to Ceram

We determined that the third option, that of Ceram becoming the internet server at each site, was clearly the most expensive option. This option predicted almost a two million dollar loss for Ceram stemming primarily from the extremely competitive nature of the internet industry. The other two options, franchising and selling the hardware kit only, both showed an expected profit of approximately one million dollars. Because the expected profits in these two options were very close, our final recommendation to Ceram was confounded. Nevertheless, we recommended Ceram pursue the second option, selling only the hardware kits, rather than the franchising option, because it had fewer overhead costs and therefore provided more opportunity to increase profits.

3.7. Conclusions and Lessons Learned

Ceram has already begun production and marketing of their hardware kits. Our application of decision analysis found the most profitable way for Ceram to distribute those kits. The work that we accomplished for Ceram taught us several important lessons about the application of decision analysis. Clearly, the most important step in this project was in formulating the problem itself--defining which decisions needed to be made, determining which variables were relevant to which options, and gathering the necessary data.

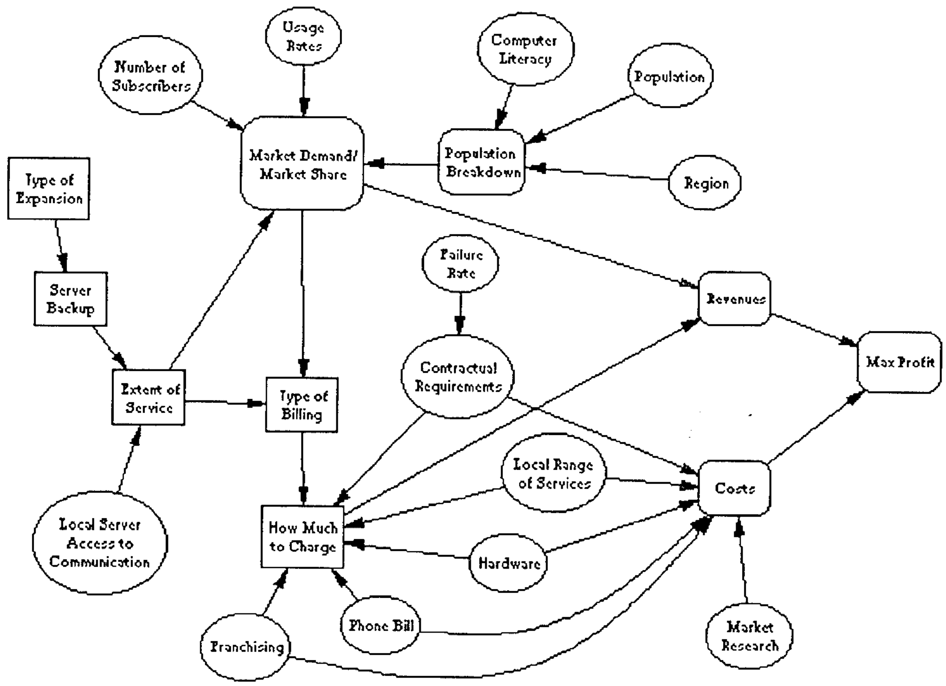

Figure 3. Original Influence Diagram for Ceram

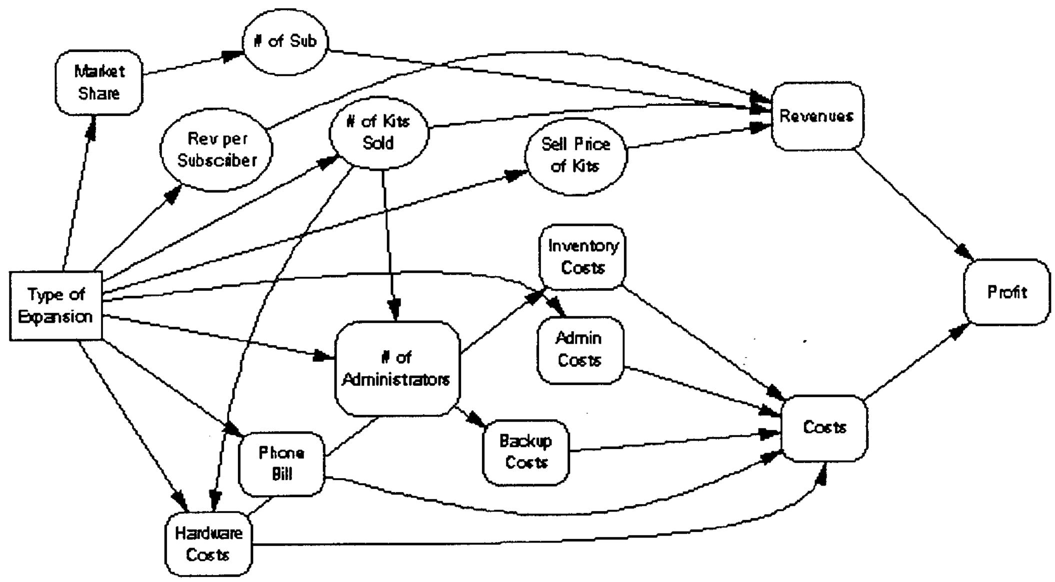

Figure 4. Final Influence Diagram for Ceram

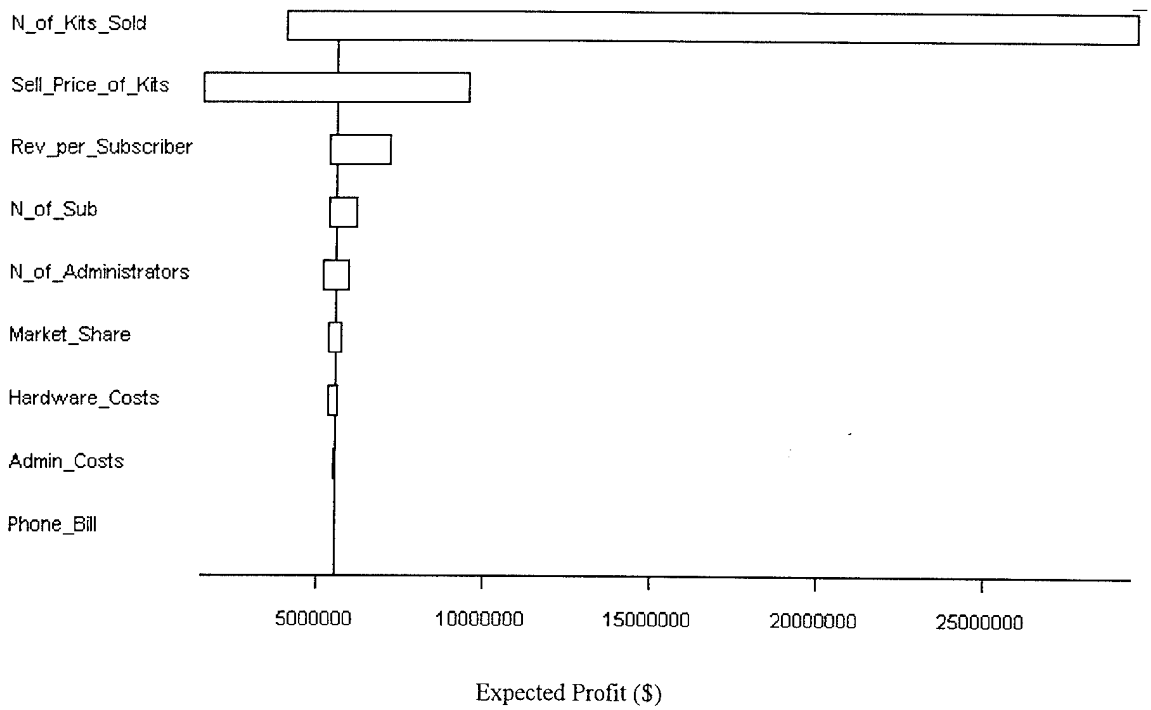

Figure 5. Tornado Diagram for Ceram

4. EMPAK INCORPORATED

4.1. Background Information

Electronic Materials Packaging Incorporated (EMPAK Inc.) is a Minnesota-based plastics company with a manufacturing plant in Colorado Springs, CO. This plant builds plastic carriers that are used to transport/hold 12 silicon wafers. Large chip manufacturers such as Intel and Motorola use these carriers within their fabrication plants.

EMPAK is building an applications laboratory within their Colorado Springs plant. The purpose of this laboratory is to test prototype carriers.

A team of United States Air Force Academy cadets worked for EMPAK to analyze what type of equipment they should put in their lab. As discussed next, we used decision analysis to analyze EMPAK's decision.

4.2. Formulation

This step was the most difficult step. EMPAK provided us with the following problem statement:

> "We are in the process of developing and installing an 'Applications Laboratory' as part of our product functional testing as those products relate and interact with our customer's process of manufacturing semiconductor chips. What we need to identify is what potential equipment requirements are necessary to determine our products affect on silicon wafers as they are introduced to our carriers. We need to determine what instruments are required with the minimal amount of cost to produce wafer level affect data for product reliability to our customers. The products we produce are injection molded process and shipping carriers that interface semi-automatically and fully automatically with automation equipment sets and are introduced to in-fab processes which may be aggressive chemicals at points."

This statement was too complex and technical. Therefore, our first job was to reduce the scope of EMPAK's problem statement. After meeting with company representatives at EMPAK,

we were able to reduce the problem statement to this: What equipment should EMPAK put in their new applications lab to maximize expected profit over the next three years?

Using EMPAK's input, we then determined there were four key variables in their decision: lab equipment, potential revenue, the costs associated with the lab, and the report quality.

Table 1 shows the different types of lab equipment and their costs being considered by EMPAK. To simplify the analysis, we grouped the lab's possible equipment configurations into three general categories, *Minimal*, *Average*, and *Maximal*. *Minimal* was defined as the least amount of equipment needed to run the lab. *Average* was the amount of equipment that would be needed to enhance the lab's performance. *Maximal* was the maximum amount of equipment that would fit in the lab.

Revenues were determined by possible contracts with companies. These contracts were up for bid over the next three years. The actual company names were proprietary information and were depicted as Company A, Company B, etc., in Table 2a. Estimated revenues of the contracts with these companies over three years are also shown in Table 2a (*Rev Yr1*, *Rev Yr2*, and *Rev Yr3*). The net present value total (*NPV Total*) in the last column of Table 2a was computed using a discount rate of 6%.

Table 2b also shows 10-50-90 values (low-mid-high) for the cost of building the lab (*Startup*) and the cost of operating the lab for three years (*Op1*, *Op2*, and *Op3*). *NPV* in Table 2b was also computed using a discount rate of 6%.

EMPAK's initial influence diagram (Figure 6) had two decision nodes, five value nodes, and three chance nodes. At this point, we considered analyzing two decisions: what equipment to put in the lab as well as how much testing to do externally. We assumed input into the external

testing decision would come from engineers as well as customers. Customer's rating of the lab, accuracy of the lab, and new sales generated were uncertain.

We then met with EMPAK again. After explaining our influence diagram in Figure 6, we gathered more information from EMPAK. This resulted in a new influence diagram as shown in Figure 7. Note how our simple influence diagram expanded to include four decisions and many more inputs and uncertainties. However, we did not have the time, knowledge, nor resources to utilize this in-depth influence diagram, so we met again with EMPAK to narrow the scope of our analysis.

As a result, EMPAK's critical decision was what equipment would go into the lab. Using this decision as a basis for our model, we developed our final influence diagram (Figure 8). This influence diagram turned out to be very similar to the initial influence diagram we developed. Revenue was the sales generated if EMPAK obtained a contract with Companies A through M. However, EMPAK estimated that only 45% of the contract value would be realized as revenue. Report Quality is EMPAK's estimate of how good the marketing report will be for the "best" plastic carrier. It is possible that even with the *Maximal* lab alternative, a good plastic will not be found and the marketing report will be poor. Likewise, even with the *Minimal* lab alternative, a great plastic carrier could be found, and an excellent marketing report could be developed.

4.3. Modeling

Implicitly shown in our final influence diagram was the financial model: *Expected Profit = Expected Revenue - Expected Cost*. *Expected Revenue* was the product of contract value and the probability of getting that contract for a given level of report quality (see Tables 2a and 3).

Expected Cost includes the equipment costs and operation costs for the lab (see Table 2b). Listed in Table 3 are each of the companies that EMPAK will attempt to sell their product to and the likelihood of obtaining a contract with each of these companies. *Max* represented the *Maximal* equipment alternative, *Avg* represented the *Average* equipment alternative, and *Min* represented the *Minimal* equipment alternative. *Ex*, *Sat*, and *Unsat* were defined as an excellent, satisfactory, and unsatisfactory reports, respectively. These were generated by EMPAK's expectations of how good the report would be for a given level of equipment. To illustrate: EMPAK estimated a 60% chance of gaining a contract with Company A for the *Maximal* equipment alternative (*Max*) and a satisfactory report (*Sat*).

4.4. Insight

We found that the *Maximal* equipment alternative generated a higher expected net profit than the other two equipment configurations (*Average* and *Minimal*). Figure 9 shows return (net profit) on investment for the three different equipment configurations. The *Minimal*, *Average*, and *Maximal* equipment configurations are represented in Figure 9 as investments of $519,555, $802,055, and $1,040,055, respectively. These values include the start-up costs and operating costs. As illustrated in Figure 9, as more equipment is added to the lab, the net profit grows at a decreasing rate.

Another insight was the pictorial representation of the net profit for the three equipment configurations with differing levels of certainty, see Figure 10. For example, the *Maximal* equipment configuration resulted in a 70% chance of making approximately $9,000,000 or less. Compare this to a 70% chance of making only $5,000,000 or less for the *Minimal* equipment.

The fact that the curve for the *Maximal* equipment configuration lies almost exclusively to the right of the other two curves shows it is the optimal solution in nearly all cases. The only exception to this occurs when EMPAK does not win any new contracts (less than a 5% chance). In this case, they would lose the amount of money they spent on equipment.

4.5. Lessons Learned

The most critical part of a real-world decision problem was understanding the decision. Once the decision was fully understood, developing models, collecting data, and analyzing the results were relatively easy. However, to do this we had to narrow the scope of EMPAK's decision problem.

Minimal Equipment	Cost ($)
Scrubber	10,000
Notch Finder	3000
Clean Room	300,000
Boat/Box Abrasion	20,000
Wet Bench	5000
Shock Tester	88,000
Table Top	0
Vacuum	0
TOTAL COST	426,000
Average Equipment Adds:	Cost ($)
Tencor	250,000
Mini Environment	10,000
Fogger	2500
MISC Robots	20,000
TOTAL COST	708,500
Maximal Equipment Adds:	Cost ($)
WEFT	200,000
Gas Analyzer	25,000
Environment Chamber	13,000
TOTAL COST	946,500

Table 1. Start-Up Costs for Different Equipment Levels

Target Customer	Rev Yr1 ($)	Rev Yr2 ($)	Rev Yr3 ($)	NPV Total ($)
Company A	954,000	1,242,000	1,485,000	3,252,210
Company B	540,000	540,000	540,000	1,443,426
Company C	362,700	499,050	693,000	1,368,179
Company D	783,000	360,000	360,000	1,361,341
Company E	450,000	450,000	450,000	1,202,855
Company F	337,500	337,500	337,500	902,142
Company G	270,000	270,000	270,000	721,713
Company H	248,400	311,400	124,200	615,765
Company I	208,800	112,500	112,500	391,563
Company J	208,800	90,000	90,000	352,647
Company K	174,600	67,500	67,500	281,466
Company L	78,300	26,100	26,100	119,011
Company M	7,200	1,800	1,800	9,906
Total	4,623,300	4,307,850	4,557,600	12,022,224

Table 2a. Estimated Revenues for EMPAK

	Startup ($)	Op1 ($)	Op2 ($)	Op3 ($)	NPV ($)
Low Cost	426,000	35,000	35,000	35,000	519,555
Mid Cost	708,500	35,000	35,000	35,000	802,055
High Cost	946,500	35,000	35,000	35,000	1,040,055

Table 2b. Estimated Costs for EMPAK

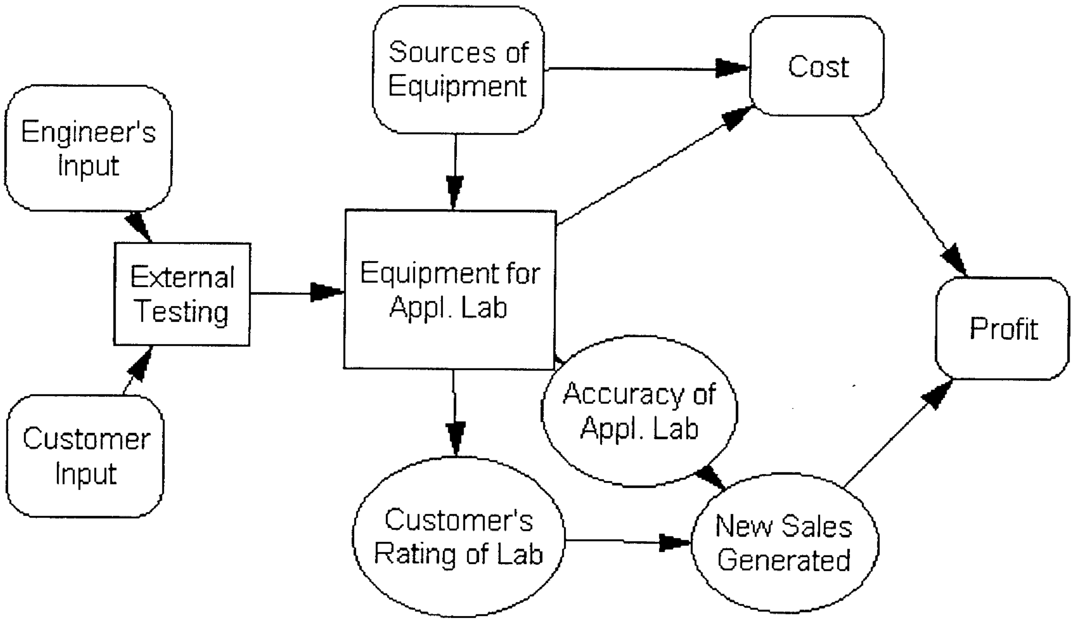

Figure 6. Initial Influence Diagram for EMPAK

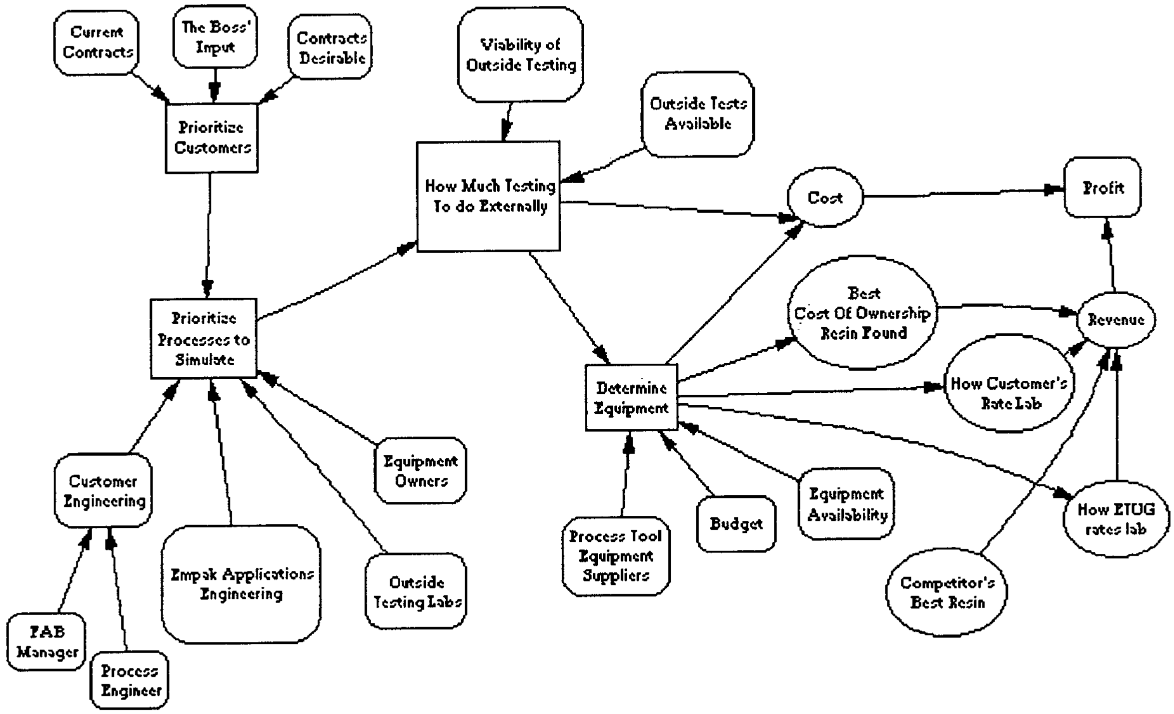

Figure 7. In-Depth Influence Diagram for EMPAK

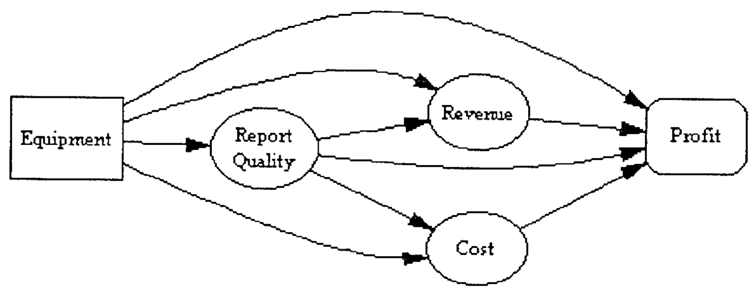

Figure 8. Final Influence Diagram for EMPAK

	Max Ex	Avg Ex	Min Ex	Max Sat	Avg Sat	Min Sat	Max Unsat	Avg Unsat	Min Unsat
Company A	65%	60%	10%	60%	55%	10%	30%	27%	10%
Company B	80%	70%	10%	65%	58%	10%	50%	42%	10%
Company C	65%	60%	10%	60%	55%	10%	30%	27%	10%
Company D	65%	60%	10%	60%	55%	10%	50%	27%	10%
Company E	50%	40%	10%	40%	30%	10%	30%	20%	10%
Company F	80%	70%	10%	65%	59%	10%	50%	42%	10%
Company G	80%	70%	10%	65%	58%	10%	50%	42%	10%
Company H	85%	83%	10%	83%	80%	10%	80%	80%	10%
Company I	50%	48%	10%	40%	28%	10%	20%	20%	10%
Company J	60%	52%	10%	52%	42%	10%	30%	38%	10%
Company K	70%	64%	10%	63%	56%	10%	60%	55%	10%
Company L	70%	62%	10%	62%	50%	10%	50%	40%	10%
Company M	70%	62%	10%	62%	50%	10%	50%	40%	10%

Table 3. Likelihood EMPAK will obtain a Contract with a Company

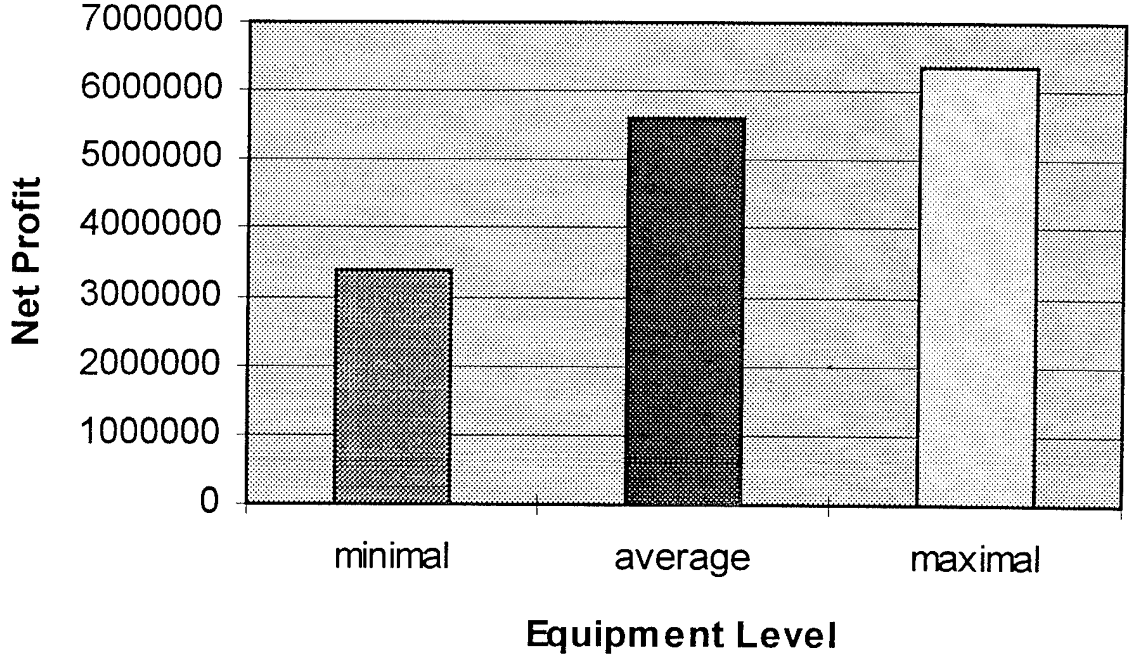

Figure 9. Return on Investment for EMPAK

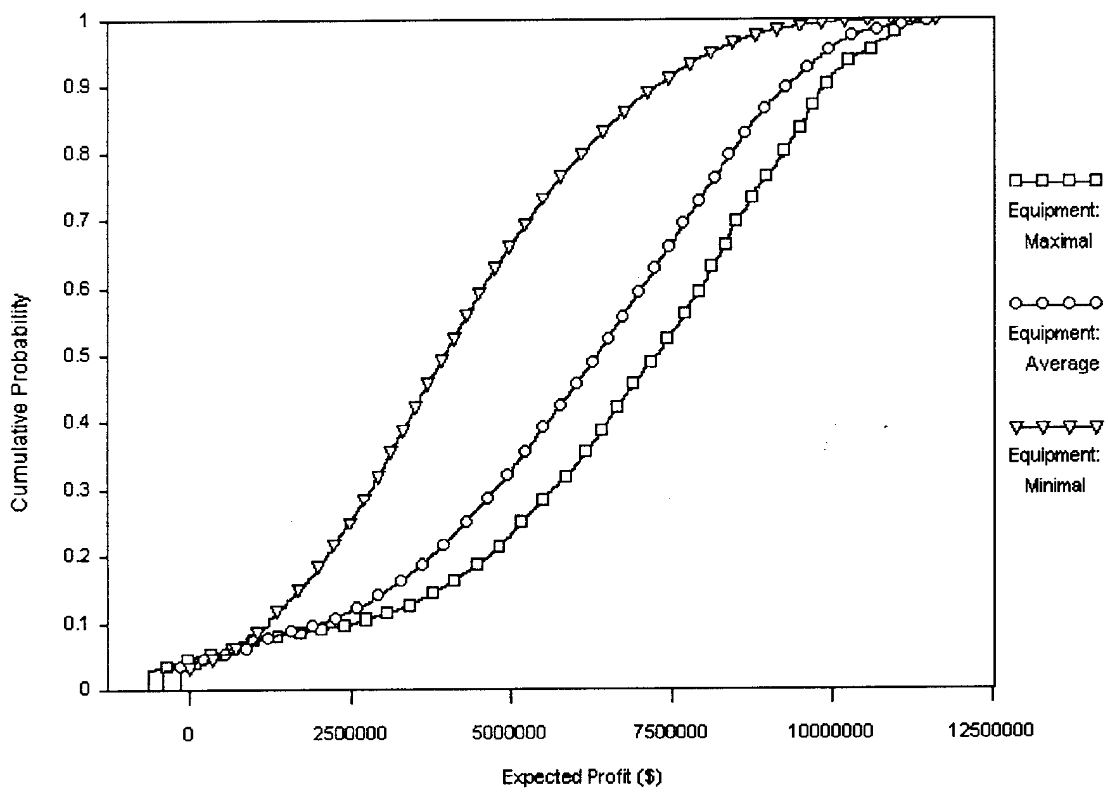

Figure 10. Comparison of EMPAK's Alternatives

5. FORD MICROELECTRONICS INCORPORATED

5.1. Problem Description

Ford Microelectronics Incorporated (FMI), a subsidiary of Ford Motor Company (FMC), currently supplies silicon micro-machined (SMM) nozzles for automotive fuel injectors. The FMC plant produces 3.8-liter engines for the Taurus/Sable vehicles which use this nozzle. The SMM nozzle design is a research and development innovation of FMI. Initially, this nozzle seemed to be a breakthrough with improvements in fuel efficiency, reliability, and reduction of exhaust pollutants. As a result, FMI recognized an opportunity to increase its market share in the nozzle industry.

With no guaranteed market for the SMM nozzle, FMI took a risk and began funding the development of the SMM nozzle. Unfortunately, during retesting FMI discovered that the initial test results were inaccurate due to miscalibrations in the original measurements. That is, there were only slight improvements in pollution control and fuel efficiency with the more expensive SMM nozzle when compared to the old inexpensive punch-plate nozzle. The increase in production costs suddenly outweighed the questionable benefits of the SMM nozzle.

With a significant amount of time, money, and manning invested in the SMM nozzle program, FMI was reluctant to simply abandon the nozzle design. However, without a customer, FMI could not expect to fund further research and development (R&D) efforts for their SMM nozzle technology. So the question was: Should FMI continue R&D of the SMM nozzle in hopes of improving the technology or cancel the program to reallocate the funds to support other programs?

5.2. Decision Analysis Approach to FMI'S Decision

After we defined FMI's decision, we then analyzed all of the contributing factors. An influence diagram was used to illustrate these factors. The original influence diagram for FMI is shown in Figure 11 and represented FMI's view of the nozzle world.

As shown in Figure 11, FMI wanted to maximize their profit. Profit was influenced by revenues and costs. There are two sources of revenues: automotive and non-automotive applications. Revenues from automotive applications were influenced by market demand from potential external and internal customers. FMI originally identified its potential external customer base as Weber, Bosch, Cummins, Nippondenzo, AC Rochester, and Siemens. Each of these companies have expressed an interest in the nozzle, but no one has signed an agreement. FMI's internal customer was FMC's Electrical-Fuel Handling Division (EFHD). Potential customers were also influenced by the results from testing the nozzle. Possible sources of revenues for non-automotive applications included: gas-range appliances and the Hewlett Packard Ink Jet Printer.

Costs were influenced by R&D, fixed costs, and production costs. Production costs were determined by volumes produced, overhead costs, and labor. And, finally the labor costs consisted of both direct and indirect labor costs.

Because of the size and intricacy of FMI's decision, and time limitations, we narrowed down the scope of their problem into a more tractable form. For example, we removed Nippondenzo, AC Rochester, Siemens, and FMC's EFHD as customers since FMI was longer considering them. Non-automotive applications were not further analyzed, because funding for the present nozzle program was expected to be depleted at the end of 1995. FMI's decision revolved around three possible customers namely: Weber, Bosch, and Cummins. A new

influence diagram was constructed to represent FMI's revised view of the nozzle world. This is shown in Figure 12.

With the revised influence diagram constructed, we then determined from FMI's experts, the likelihood a potential customer would purchase FMI's nozzle and in what quantities. Obtaining the likelihood that a potential customer would purchase FMI's nozzle was fairly straightforward even though the lead design engineer believed that the nozzle would definitely sell while the marketing head looked at it from a more business perspective and wasn't convinced it would sell. These values are shown in Table 4a.

Obtaining 10-50-90 values for the volume/quantity of nozzles purchased from each customer was difficult. Some of FMI's experts were technically oriented while others were not. These differing backgrounds made reaching a consensus time consuming. However, a consensus was reached after many meetings with FMI experts, see Table 4b. The values in Tables 4a and 4b, and the influence diagram in Figure 12 were then transformed into a financial model.

5.3. Insights

The expected profit for the nozzle program for next year was $1,590,210. As shown in Figure 13, there is a 60% chance of FMI making a profit. (This assumes that the likelihood of Weber, Bosch, and Cummins purchasing the nozzle to be 0.5, 0.2, and 0.1, respectively.) We then discovered that as the probability of Weber buying the nozzle increased from 50% to 80%, the chance of making a profit increased to 85%. On the other hand, if Weber decided not to buy the nozzle, FMI's expected profit was $472,816, assuming Bosch's and Cummins' likelihood of purchasing the nozzle were 0.2 and 0.1, respectively (see Table 5).

How does this help FMI? If the expected profit was negative, then we would have recommended that FMI abandon the nozzle program and devote their funds and resources to a more profitable program. However, the model showed that even if you eliminate Weber as a customer, then FMI could still make over $400,000 in expected profit next year. This profit would fund the program for the following year and may be reason enough to continue developing the nozzle because it would be financially self-supported. We have also seen that as the likelihood of Weber buying the nozzle increased, the expected profit increased.

What can FMI do to increase the likelihood of the customer buying? FMI could lower the price of the nozzle. FMI's nozzle price is dependent upon market demand. Our analysis suggested that FMI could possibly lower its nozzle price to increase the likelihood of a company purchasing the nozzle and still make a profit.

Marketing is always a viable option to increase the likelihood of a customer buying the nozzle. For example, FMI discovered that FMC was expressing more of an interest in the SMM nozzle. Promoting this interest to other potential customers could be a beneficial marketing scheme. For example, Weber and Bosch presently supply FMC with nozzles. If they are convinced that FMC is going to use the SMM nozzle in the future, they may purchase the nozzle to prepare for FMC's future demands. Besides marketing, FMI could continue R&D to possibly improve the nozzle, thus increasing the chance of selling the nozzle.

5.4. Recommendations

Our analysis helped the decision makers at FMI evaluate the potential consequences of their decision concerning the SMM nozzle. The information provided in our analysis better

equipped FMI to make a decision concerning their nozzle production. Our information was based on the range of possible profits or losses associated with the purchasing potential of each customer. According to our analysis, we recommended that the SMM nozzle program be continued.

5.5. Benefits of Decision Analysis Consulting Project

Having undergraduate students participate in an actual consulting project was extremely beneficial. For example, we learned the difficulties of dealing with people to get information versus looking it up in a book. The complications that arose in formulating FMI's decision problem and defining the influencing factors would have been difficult to simulate in a classroom. We are familiar with taking numbers from a problem, plugging them into a few equations or a computer program, and then writing up the results. This project challenged more than just our numerical abilities. It challenged our abilities to deal with people by starting from scratch to define and formulate a real problem and present the results to an organization that had very high expectations of us. We provided FMI with insight to one decision, but they provided a learning experience that exceeds what a classroom could offer.

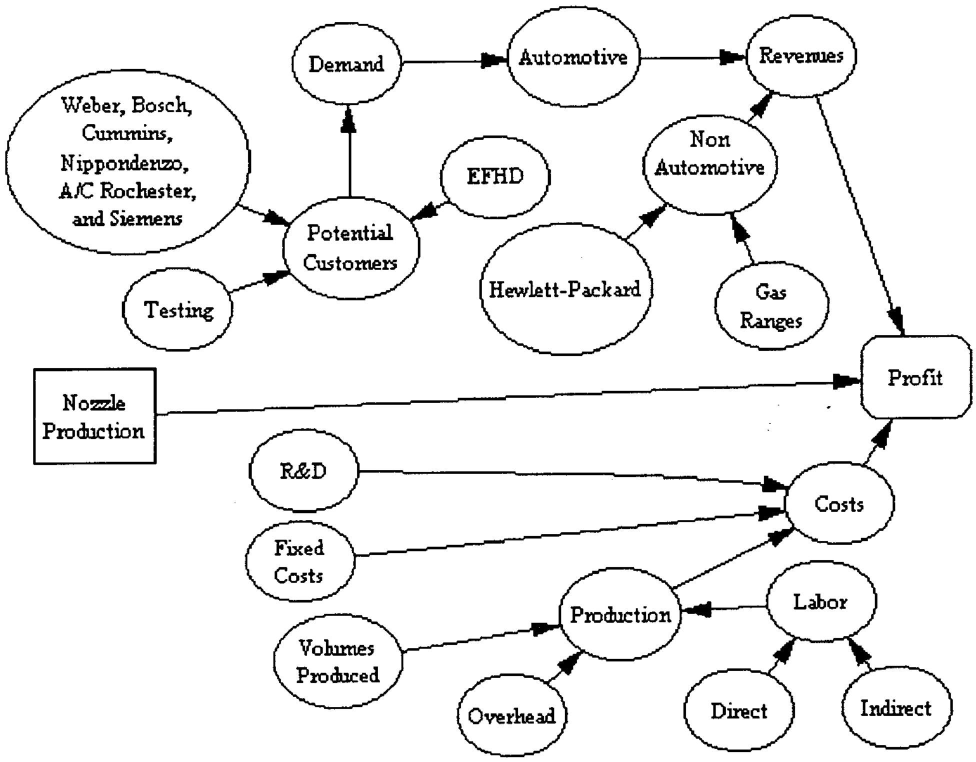

Figure 11. Original Influence Diagram for FMI

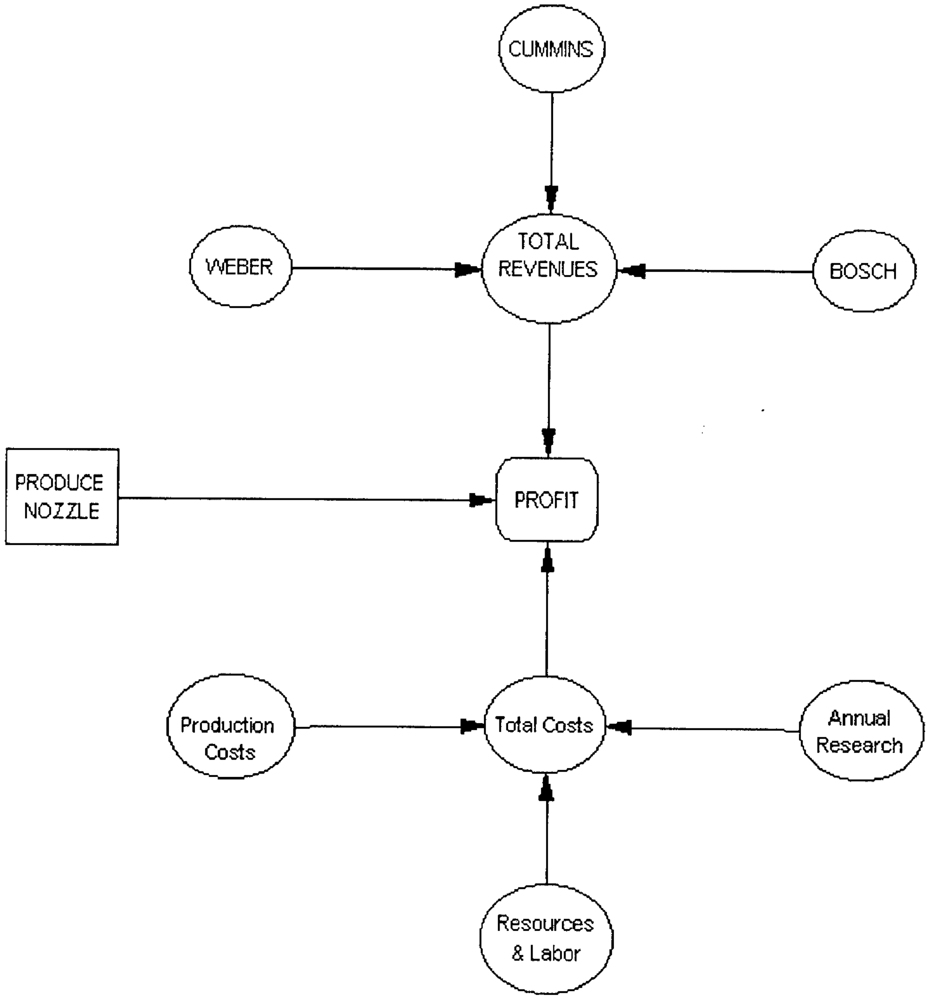

Figure 12. Revised Influence Diagram for FMI

Company	Likelihood of Purchasing
Weber	0.50
Bosch	0.20
Cummins	0.10

Table 4a. Likelihood of Weber, Bosch, and Cummins Purchasing the SMM Nozzle

Company: Weber (Planar Nozzle)

Volumes	Unit Cost ($)	Unit Price ($)	Unit Profit ($)
4,000,000	0.65	1.10	0.45
6,000,000	0.63	1.00	0.37
8,000,000	0.62	0.95	0.33

Company: Bosch (Compound Nozzle)

Volumes	Unit Cost ($)	Unit Price ($)	Unit Profit ($)
2,000,000	0.624	1.400	0.776
5,000,000	0.624	1.400	0.776
10,000,000	0.624	1.400	0.776

Company: Cummins (Planar Nozzle)

Volumes	Unit Cost ($)	Unit Price ($)	Unit Profit ($)
100,000	0.24	0.80	0.56
300,000	0.24	0.80	0.56
600,000	0.24	0.80	0.56

Table 4b. 10-50-90 Values for Possible Sales Volumes

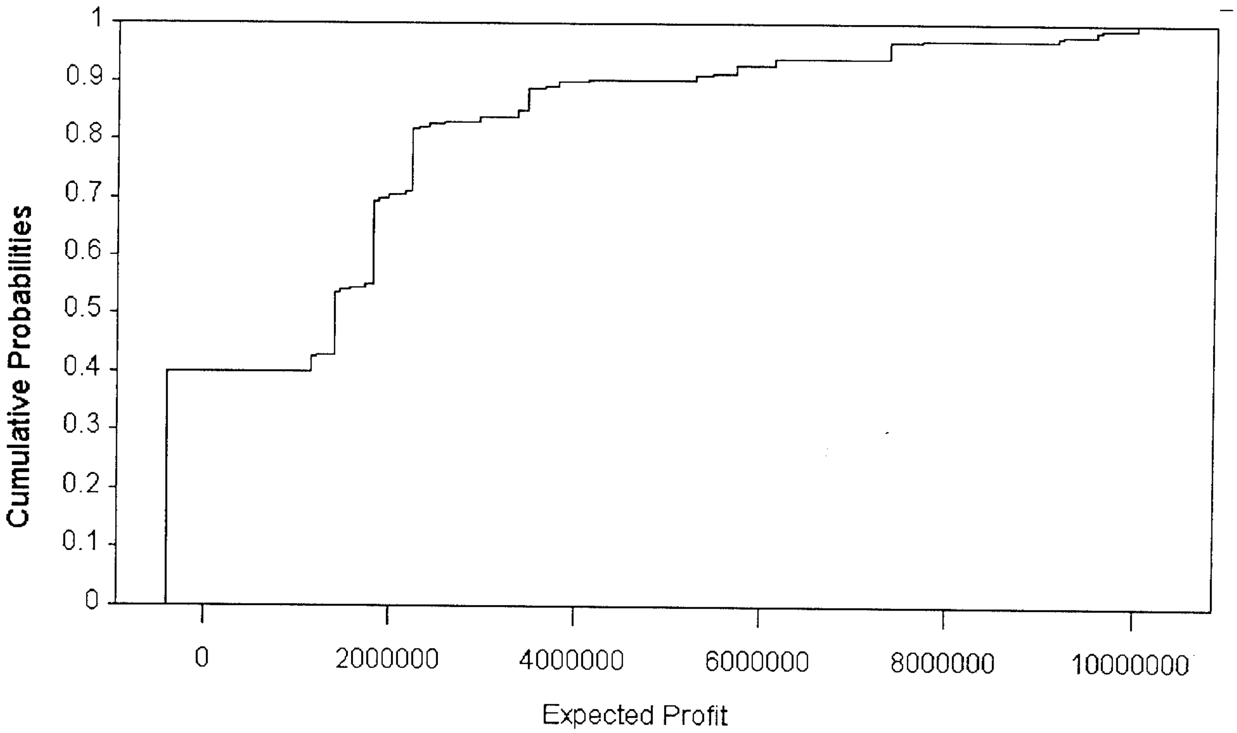

Figure 13. Cumulative Risk Profile for FMI

Likelihood that Weber Purchases	Expected Profit ($)
0.0	472,816
0.2	919,773
0.5	1,590,210
0.6	1,800,000
0.7	2,037,000
0.8	2,260,000
1.0	2,707,600

Table 5. Summary of Sensitivity Analysis for FMI

6. L0CKHEED TECHNICAL OPERATION COMPANY

6.1. Introduction to the Problem

Lockheed Technical Operations Company (LTOC) has a computer maintenance contract with military installations in the Colorado Springs area (NORAD, Peterson AFB, and Falcon AFB). These contracts required that LTOC get a computer system back on-line quickly, after it fails, by repairing the damaged parts of the system preferably without replacing the entire system. According to these contracts, LTOC must have a specified amount of replacement parts in inventory for the computer systems and "alert-ready" technicians.

The decision facing LTOC was whether to obtain commercial contracts instead of relying solely on the current military contracts. If LTOC decided to support commercial contracts its first-year goals were:

1) Establish a commercial maintenance line of business with a minimum of ten new contracts in the Colorado Springs and Pueblo area.
2) Increase the income for LTOC.
3) Exploit currently used spares that are above and beyond the minimum military contracts. (LTOC uses the standard of one spare part per ten parts they are contracted to maintain, and because of this LTOC has several spares that are not currently needed.)
4) Increase LTOC maintenance capabilities by exposure to new customers.
5) Reduce reliance on military contacts.

LTOC was scheduled to make a decision on whether to expand their computer maintenance activity to the civilian marketplace. Their approach was to do a market survey to find out how many potential civilian customers were in the Colorado Springs and Pueblo area. If the number of potential customers was too low, an expansion into the civilian marketplace would not be possible. Next, LTOC was going to conduct a worst-case and best-case analysis. The worst-case analysis concentrated on a computer system requiring the purchase of the largest

number of spare parts. The best-case analysis used a computer system with the most spare parts in inventory. From these two pieces of information, LTOC was going to decide whether or not to expand into the civilian marketplace. This is where my classmates and I began to help them with their decision.

6.2. Initial Contact

All prior contact before our initial meeting was between our instructor and LTOC's Program Manager of Marketeering. On the day of our initial meeting, we were suppose to meet with the Program Manager of Marketeering and the Program Manager of Service; however, only the Program Manager of Service was present. This absence caused a communication breakdown between the Program Manager of Marketeering and the Program Manager of Service. The Program Manager of Service did not know exactly what we would be able to do for him and what information he could release to us, but he did provide us with access to his maintenance staff.

As a result, we began to obtain information from LTOC's maintenance experts. This task was easily accomplished because the entire maintenance depot only consisted of six people. The problem we ran into was that the experts believed that each variable/input did not vary, as shown in the initial influence diagram (Figure 14). This was very disconcerting to us, so we re-evaluated our situation.

6.3. On the Right Track

We finally met the Program Manager of Marketeering. During this meeting, we redirected our focus and were provided with previously non-releasable information.

LTOC has over 40 computer systems in their inventory. We ideally would have obtained information on each of these computer systems, but LTOC did not have all the necessary information nor the time to do this; therefore, we assumed three "generic" types of computer systems (Type A, Type B, and Type C) to represent LTOC's entire inventory. The amount of spare parts to be purchased was used to categorize each generic type of computer system.

LTOC was able to provide all the costs and other related information in a spreadsheet model. This model provided very useful information, but it also had some inherent problems. One of these problems was that LTOC had some difficulty identifying the equations and parameters in the model. This made it difficult to check the accuracy of the spreadsheet model. Another problem was that the numbers in the spreadsheet represented values that LTOC believed to depict a worst-case scenario. This made future assessments more difficult since LTOC was biased with these worst-case values. We also discovered several other discrepancies, which we corrected.

In the process of correcting these problems, we clearly identified the parameters/variables and their interrelationships, see Figure 15 and Table 6. We then discussed worst-case and best-case scenarios with LTOC experts. This was difficult at first, but after continued work we were able to better communicate what was needed.

6.4. Results

From the tornado diagram, (see Figure 16) we noticed that the most sensitive variable was *Percent DSMC*. The *Number of Contracts* was also very sensitive to the profit. We then assessed 10-50-90 values for these sensitive variables.

Our next step was to explain how setting *Percent DSMC* to different levels would affect LTOC's profit. As it turned out, the break-even point for *Percent DSMC* occurred around 40%, see Figure 17. So, LTOC has the flexibility to decrease *Percent DSMC* from its current level of 65% and still make a profit. Even though, LTOC would make less money per contract if they lowered *Percent DSMC*, they may be able to get more contracts.

Type A computer system profitability was volume dependent. This insight really interested LTOC since they wanted to know at what point they broke even. We determined that LTOC began to make a profit with three Type A computer systems, see Figure 18. We also showed that at least one contract of a Type B or C computer system would make LTOC profit. As shown in Figure 19, LTOC would make a considerable amount of profit each month, with little to no chance of losing money.

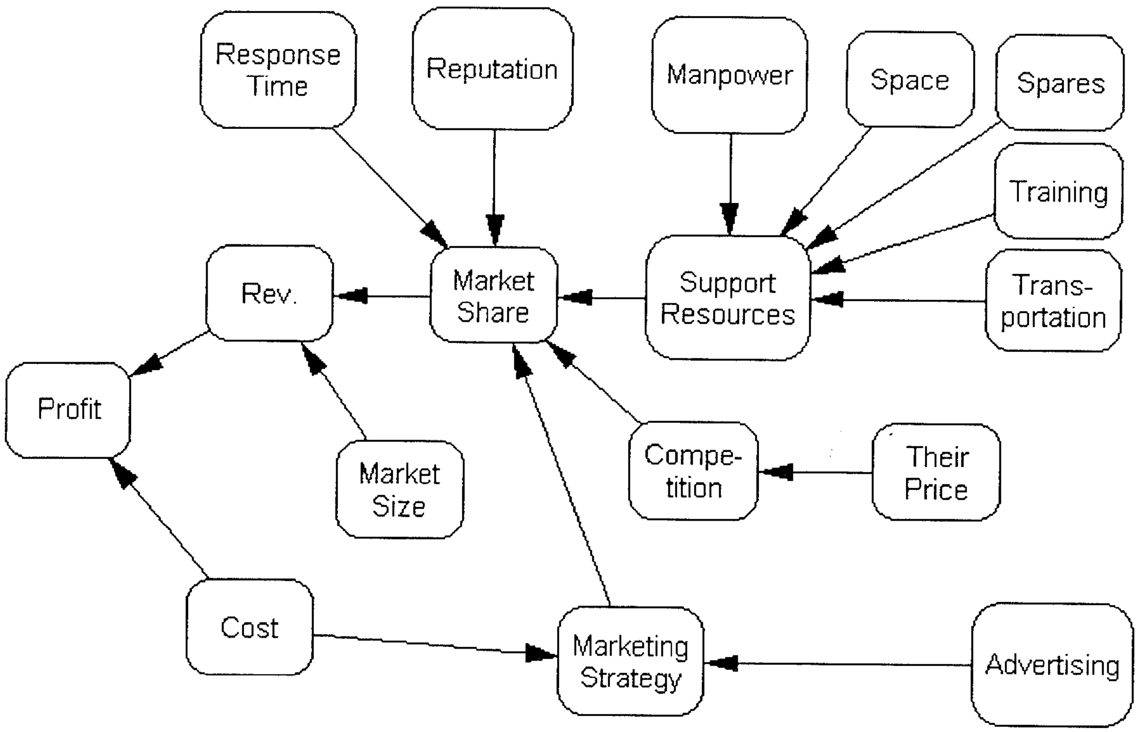

Figure 14. Initial Influence Diagram for LTOC

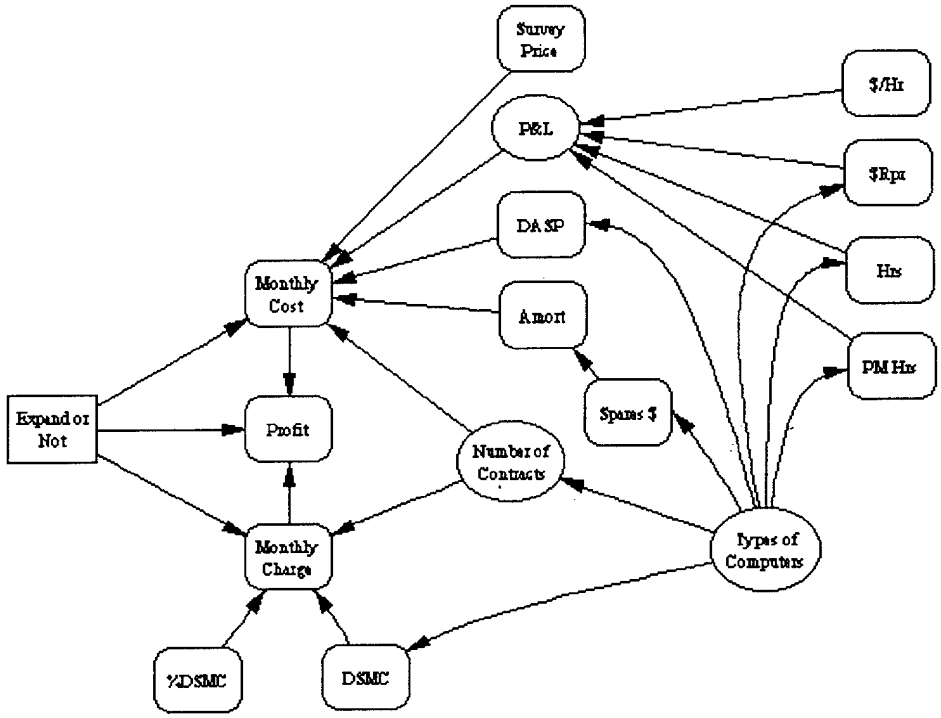

Figure 15. Final Influence Diagram for LTOC

Spares ($)	Amount of components (i.e., terminal, keyboard, mouse, monitor, and printer) of a computer system that LTOC had to purchase. LTOC's standard is one spare component for every ten computers maintained.
Amortization ($) (Amort)	Price charged to the customer for each component. It is computed by amortizing 50% of the cost of the spare component over five years.
Repair ($ Rpr)	Maximum amount that may be spent to repair a component.
Repair (Hrs)	Time spent actually fixing a computer component.
Maintenance (PM Hrs)	Set amount of time for annual upkeep.
Labor Wages	Technicians' salaries and overhead costs. Set at $30 per hour.
Parts and Labor ($) (P&L)	Annual cost for repairing a component. Parts and Labor = [Repair + Maintenance] * Labor Wages + Repair
Digital Assisted Service Plan (DASP)	Monthly cost for Digital to repair certain components.
Survey Price	An one-time cost that LTOC will spend to find companies that have computers that LTOC could maintain.
Monthly Costs	Monthly Costs = [Parts and Labor/12 + DASP] * Number of Contracts + Amortization
DEC Service Monthly Charge (DSMC)	Price that Digital Electronic Corporation (DEC) charges to maintain the computers of their customers. This is used as a reference because most civilian companies have their computers serviced by the company from which they purchased the computer system. We looked at DEC systems only.
Percent DSMC	Fraction of DSMC that LTOC will charge its customers for maintenance. LTOC's goal is to charge 65% of DSMC.
Number of Contracts	Number of computer systems/types that each potential commercial customer may have at their locations.
Types of Computers	Types A, B, and C.
Monthly Charge	Monthly Charge = Percent DSMC * Number of Contracts
Profit	Profit = Monthly Charge - Monthly Costs

Table 6. LTOC's Variables

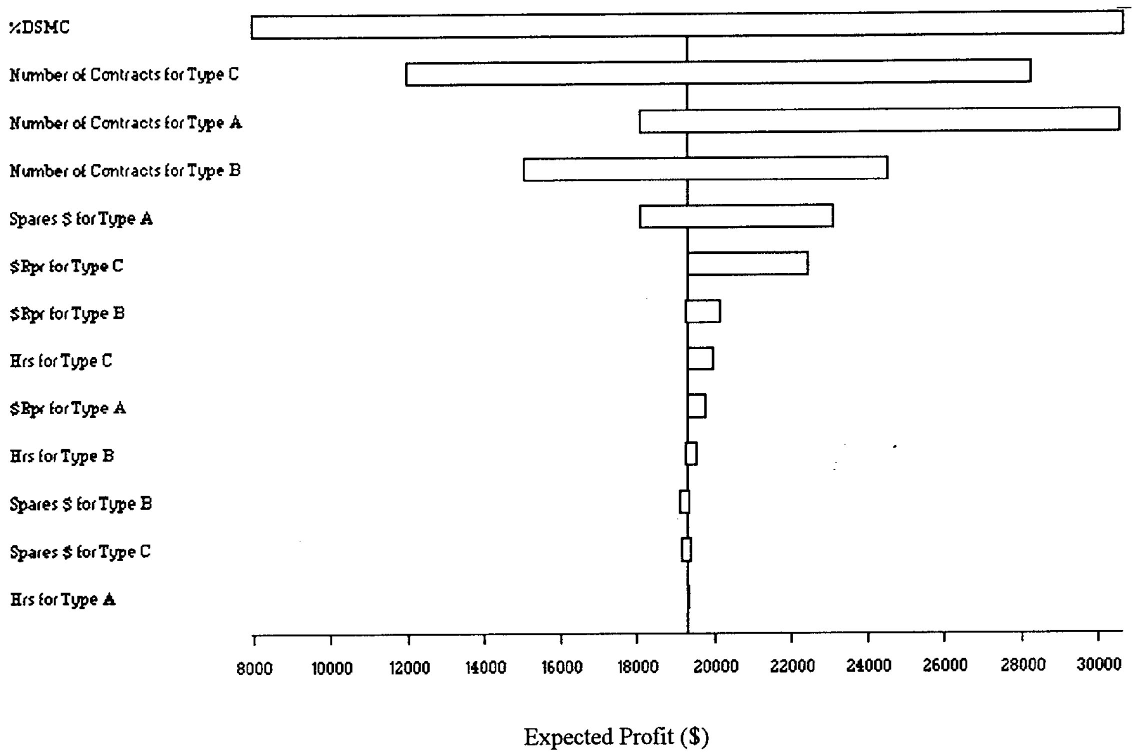

Figure 16. Tornado Diagram for LTOC

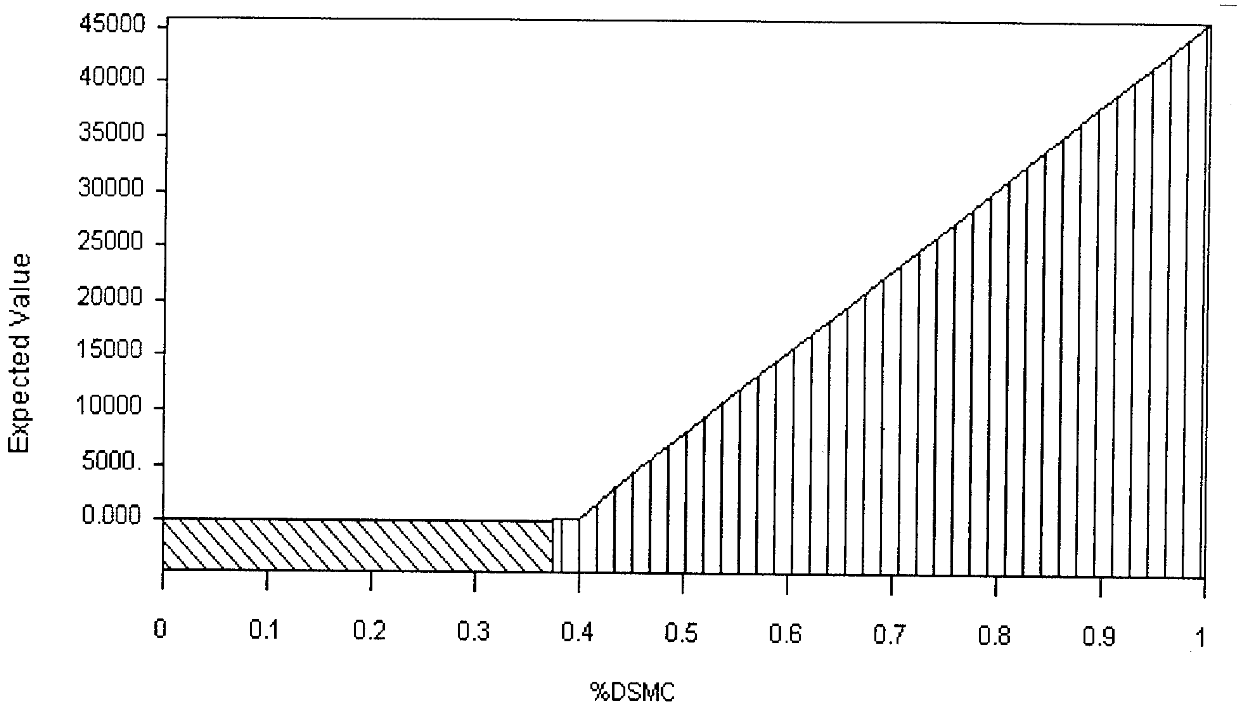

Figure 17. Break-Even Point for % DSMC

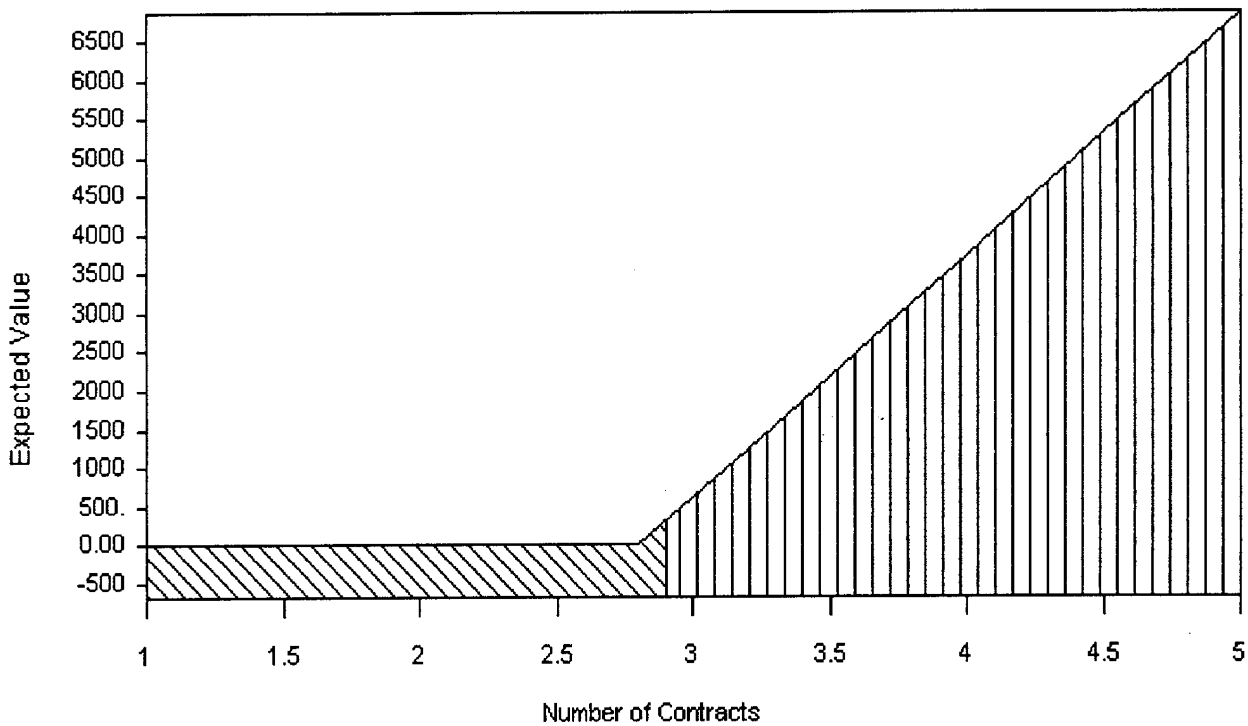

Figure 18. Break-Even Point for the Number of Contracts for Type A Computer System

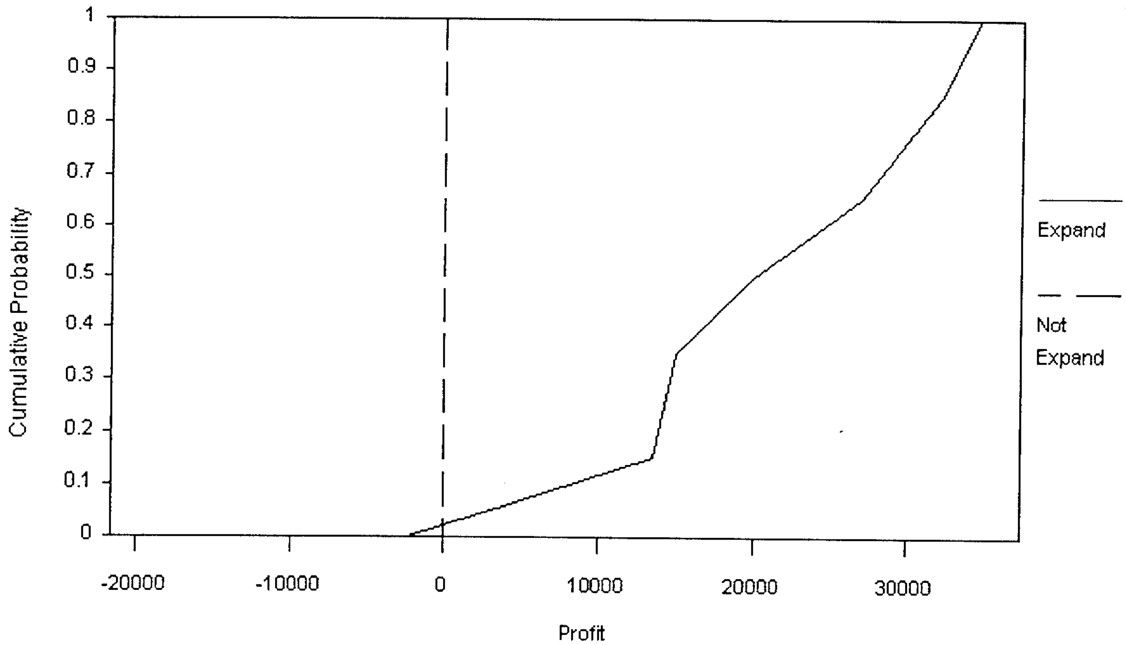

Figure 19. Cumulative Risk Profile for LTOC

7. SYSTEMS INTEGRATION SOFTWARE INCORPORATED

7.1. Introduction to the Problem

Systems Integrated Software (SIS) Incorporated was trying to determine in what markets to introduce their new product. SIS had already chosen the Department of Defense (DOD) and General Motors (GM) as their first two markets/customers. These two were selected because the product was initially tailored to solve problems for the DOD and a prototype was already developed for GM. SIS was also considering a possible future market in the telecommunication industry. Therefore, our goal was to provide insight if it would be profitable for SIS to expand into the telecommunications market.

This problem may seem fairly straight forward; however, there were some underlying problems. One was that SIS's new product was extremely complex. It is a software tool to assist with the integration of highly complex distributed systems.

Another problem was that the product has not fully matured so there was not a working model to physically demonstrate what the product can do. Also, finding a market for a entirely new product can be extremely difficult since no markets currently exist. These problems added to the difficulty of our analysis effort.

7.2. What We Did

The first and the most important step in decision analysis is to clearly define the problem. For us, that meant understanding exactly what SIS's product was supposed to do. Due to the complexity of the product, this was also where we spent most of our time.

The initial meetings with the Chief Executive Officer (CEO) and Chief Operating Officer (COO) were extremely frustrating since the product was so complex and the CEO and COO could not explain the specifics to us. As a result, we decided to get a different perspective by talking to the people who were actually developing the product. After meeting with the product developers, we finally felt that we had a general understanding of what the product could do.

Next, we developed an influence diagram of SIS's decision so that we were on the same "wavelength" as the people making this decision. The initial influence diagram for SIS can be seen in Figure 20. The decision that SIS was facing was whether or not to expand into the telecommunications market. Their overall goal was to make a profit. Next, we needed to ascertain from SIS what influenced profit. As a result, we met with SIS's marketing expert along with the CEO and COO. The purpose of this meeting was to determine the key factors that influenced the profit opportunities of this expansion. From this meeting, we determined that costs and revenues were the key factors that influenced SIS's profit opportunities.

Further discussion with SIS revealed that costs were influenced by the developmental costs of tailoring the product for the telecommunications market, the cost of marketing the product, and the cost of hiring new employees needed to work in the telecommunications market. Revenues were influenced by the overall market size for this product and SIS's share of the market. At this point, the problem was decomposed into a fairly simplistic model, making it easy to understand, see Figure 20. The next step, obtaining numerical values for these costs and revenues, was extremely difficult.

Since costs and revenues were uncertain, we needed to obtain 10-50-90 values from SIS's experts. After talking to the CEO again, we soon discovered our next major obstacle. There

were no experts! That is, there was no one in the company who knew enough about the telecommunications market for this product to provide us with realistic 10-50-90 values for the five uncertainties mentioned above. However, there was one person in the company who had worked for a major phone company before.

Therefore, we met with this employee and tried to obtain 10-50-90 values from him since he knew the capability of SIS's product and its potential applicability in the telecommunications market. After talking to him, we soon discovered that he could only give us estimates on the costs and the revenues in general. This resulted in a more simplistic influence diagram as shown in Figure 21. The only variables now influencing profit were revenues and costs. Table 7a and Figure 22 show 10-50-90 values for revenues while Table 7b and Figure 23 show 10-50-90 values for costs.

The 10-50-90 values for both revenues and costs were only provided for the first and fifth years only. Knowing that it would take time for SIS to be totally integrated into the marketplace, the expert believed that the values for the first year started low, and then began to increase until the fifth year. With concurrence from SIS, we then linearly approximated the values between the first and fifth year.

7.3. Results

We determined that the expected net present value of SIS's decision was about $21 million. With the opportunity to make this amount of money, SIS's CEO and COO are currently working on ways to make this expansion happen. SIS is also trying to arrange a meeting with a major telecommunications company's to determine their needs.

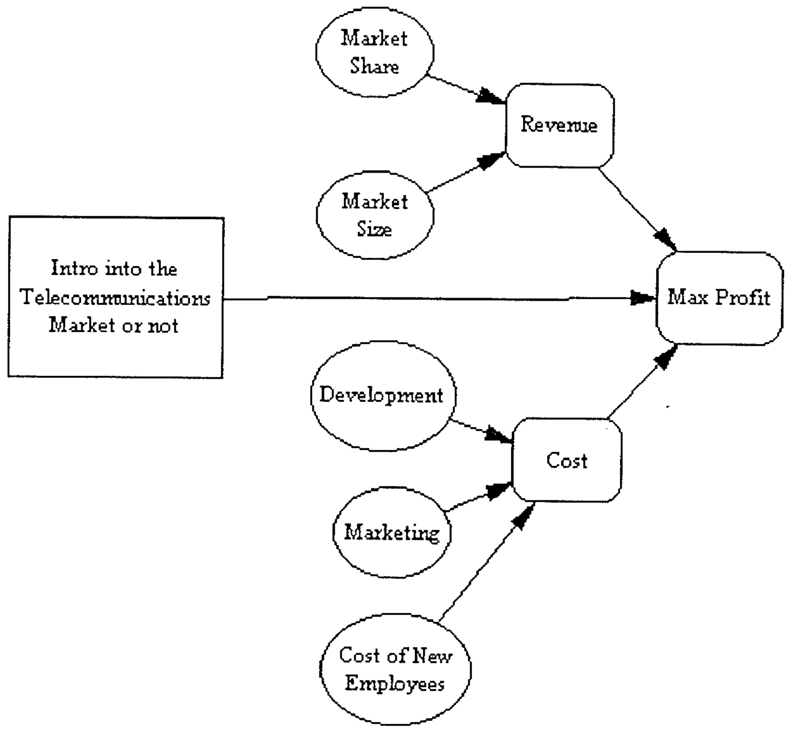

Figure 20. Initial Influence Diagram for SIS

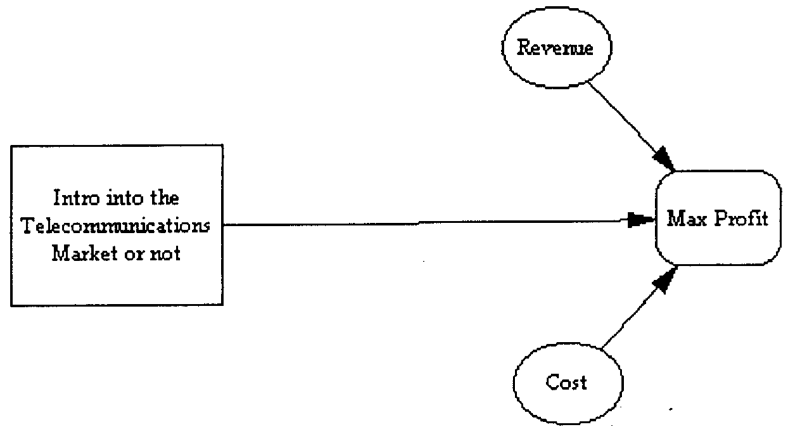

Figure 21. Final Influence Diagram for SIS

Year	10 value	50 value	90 value
1	500,000	1,000,000	2,000,000
2	1,250,000	5,000,000	8,750,000
3	2,500,000	10,000,000	17,500,000
4	3,750,000	15,000,000	26,250,000
5	5,000,000	20,000,000	35,000,000

Table 7a. 10-50-90 Values for SIS's Revenues ($)

Year	10 value	50 value	90 value
1	165,000	400,000	1,000,000
2	412,500	2,000,000	4,375,000
3	825,000	4,000,000	8,750,000
4	1,237,500	6,000,000	13,125,000
5	1,650,000	8,000,000	17,500,000

Table 7b. 10-50-90 Values for SIS's Costs ($)

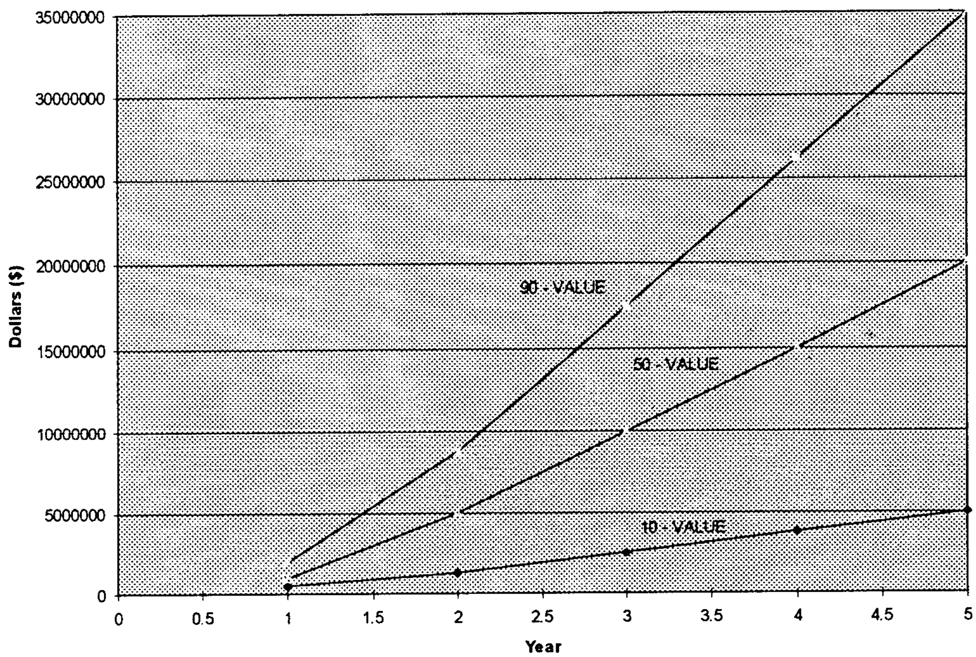

Figure 22. 10-50-90 Values for SIS's Revenues

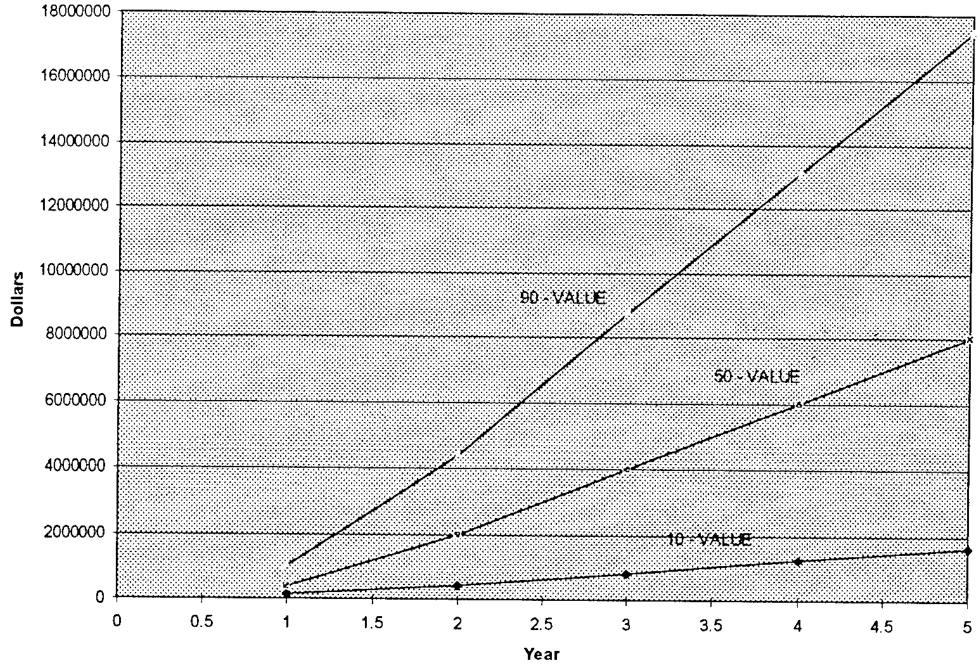

Figure 23. 10-50-90 Values for SIS's Costs

8. CONCLUDING REMARKS

Each client felt decision analysis helped them focus on their decision and each plans to act on the recommendations of their student consulting team. Equally as important, students learned how to approach "real" decision problems in a logical and systematic manner. As tomorrow's Air Force leaders, these students will be faced with many tough decisions, and this course forced the students to think analytically and critically, as well as clearly communicate a complex decision.

8.1. Lessons Learned from an Instructor's Perspective

(1) The instructor should find the consulting projects since the students do not have the expertise nor the time to find suitable projects.

(2) The instructor should be actively involved during the consulting project. Consulting is not easy and students need guidance and direction. This is especially true for the initial meetings with the client.

8.2. Lessons Learned from a Student's Perspective

(1) "The first meeting was a reality check. This wasn't a textbook problem with a textbook answer."

(2) "I wasn't aware of how hard it would be to 'pull' information from the 'tight' grasps of the client."

(3) "The ability to simplify a problem, model it and provide genuine insight was very rewarding."

(4) “Formulating the problem, as hinted at in class and as we expected, probably took us the longest amount of time. It was also the most frustrating process because sometimes it felt like we were working backwards and just moving further away from the solution. However, we realized that this first step was the most critical part of the process; it would be a waste of time to solve the wrong problem.”

(5) “Be patient, especially in the beginning. Trying to rush through a realistic project like this will just result in poor technique and questionable results.”

(6) “The most important lesson I learned from this experience is that clarity and proper definition of the problem is essential early. In my case, the client was almost reluctant sometimes to give information, I think because they and I were not talking about the same thing. It is difficult to get the information you want from your client if your client has a totally different perspective of the meaning of a variable or the overall purpose of the study. Emphasis should be placed on better reading the client for their perspective on the problem. If you start out with different views, the end product will be of no use to the client.”

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